



NISOI

Orbital Debris Characterization via Laboratory Optical Measurements

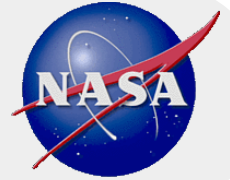
Unclassified

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Orbital Debris Research & Science Operations

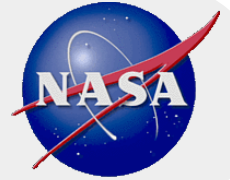
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Agenda

- **Optical Measurement Center (OMC) overview**
- **Ongoing tasks**
 - I. Rocket body investigations
 - II. Phase functions
 - III. Fragmentation debris characterization (photometric and spectral data)
 - IV. Development of Optical Size Estimation Model (OSEM)



Introduction

Optical observations of orbital debris offer insights that differ from radar measurements (specifically the size parameter, wavelength regime, and altitude range). For example, time-dependent photometric data yield lightcurves in multiple bandpasses that aid in material identification and possible periodic orientations. These data can also be used to help identify shapes and optical properties at multiple phase angles. Capitalizing on optical data products and applying them to generate a more complete understanding of orbital space objects is a key objective of NASA's Optical Measurement Program, and the primary reason for the creation of the Optical Measurements Center (OMC). The OMC attempts to emulate space-based illumination conditions using equipment and techniques that parallel telescopic observations and source-target-sensor orientations.



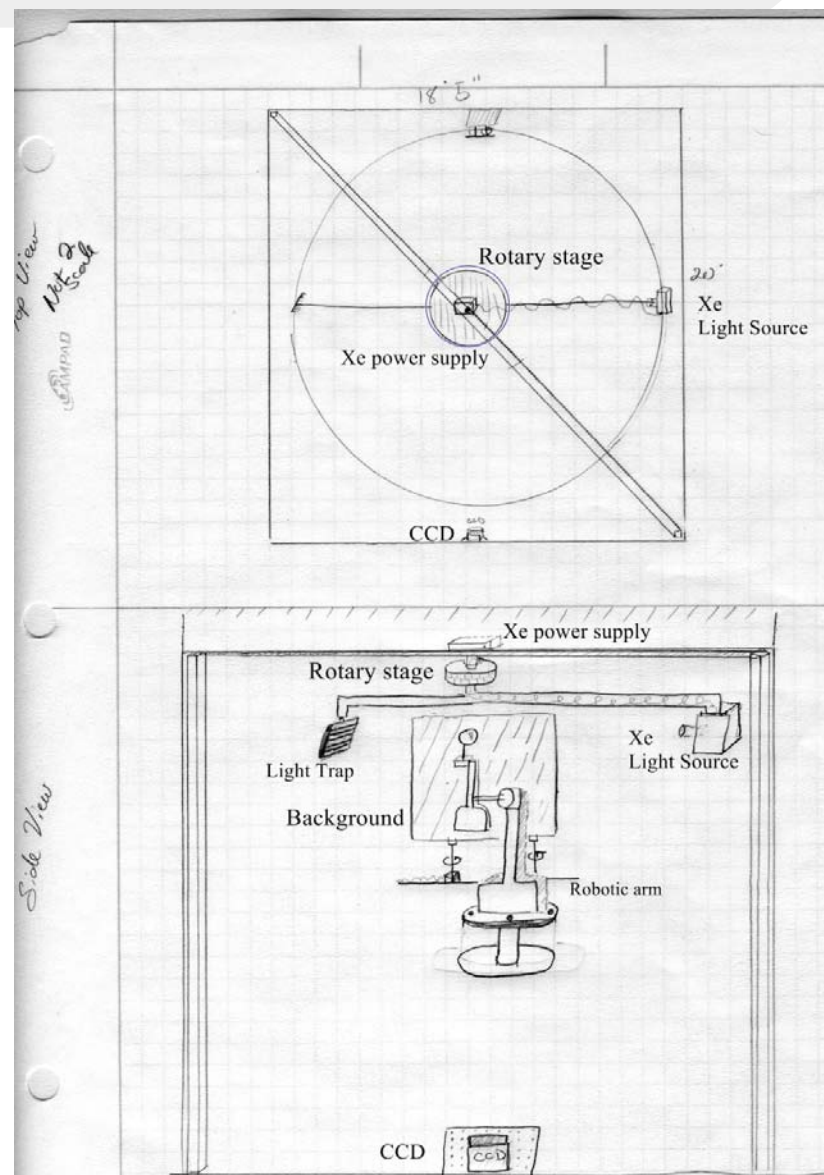
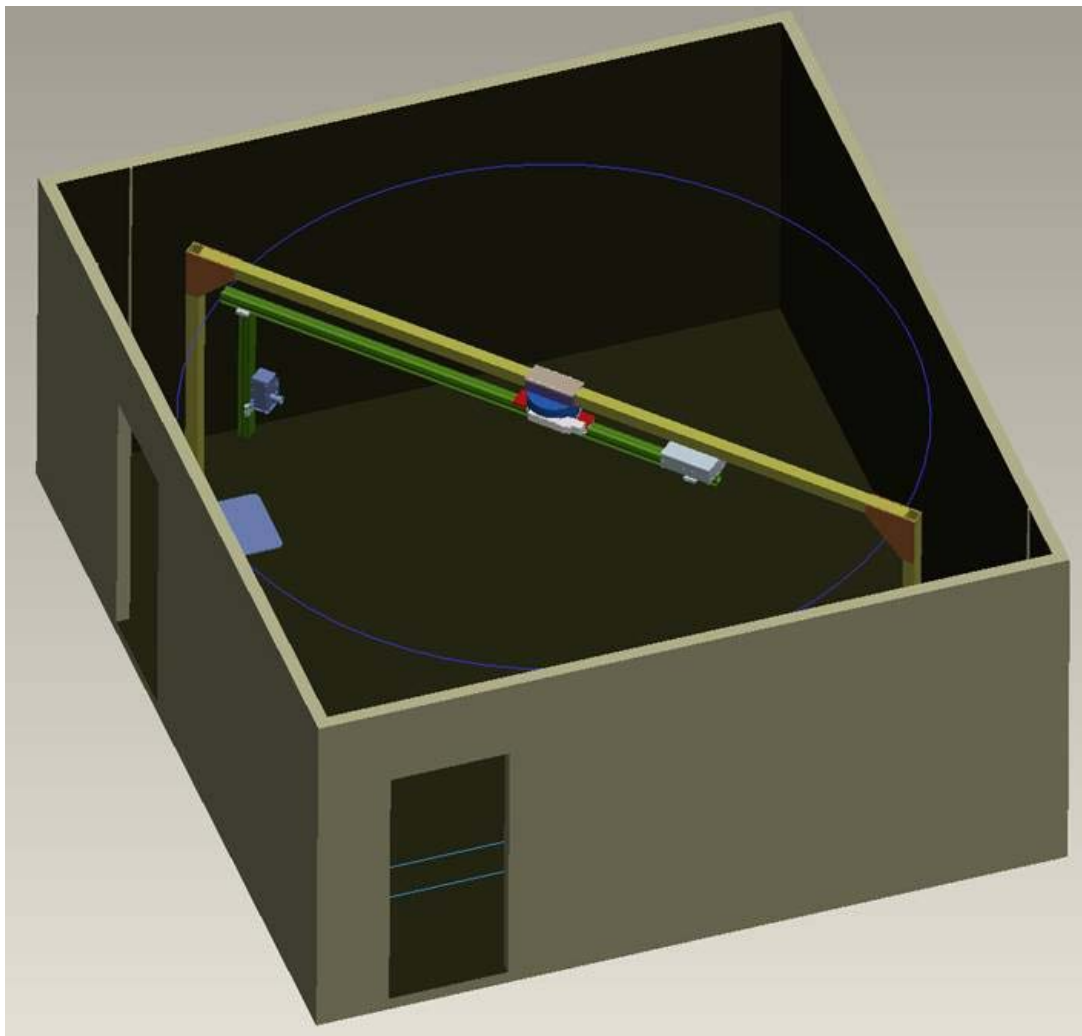
Equipment

The OMC consists of the following principle instruments:

- **ASD field spectrometer: high-resolution reflectance spectrometer with a range from 300-2500 nm .**
- **SBIG CCD camera (1024x1536 pixels); attached filter wheel uses Johnson/Bessell blue, visible, red, and infrared filters.**
- **Newport 75 W Xenon arc lamp used to simulate the solar illumination through the spectral range of 200 to 2500 nm.**
- **ST robotics R17 robotic arm (*on long-term loan from Boeing*)**
- **ESCG custom-built rotary arm with potentiometer**

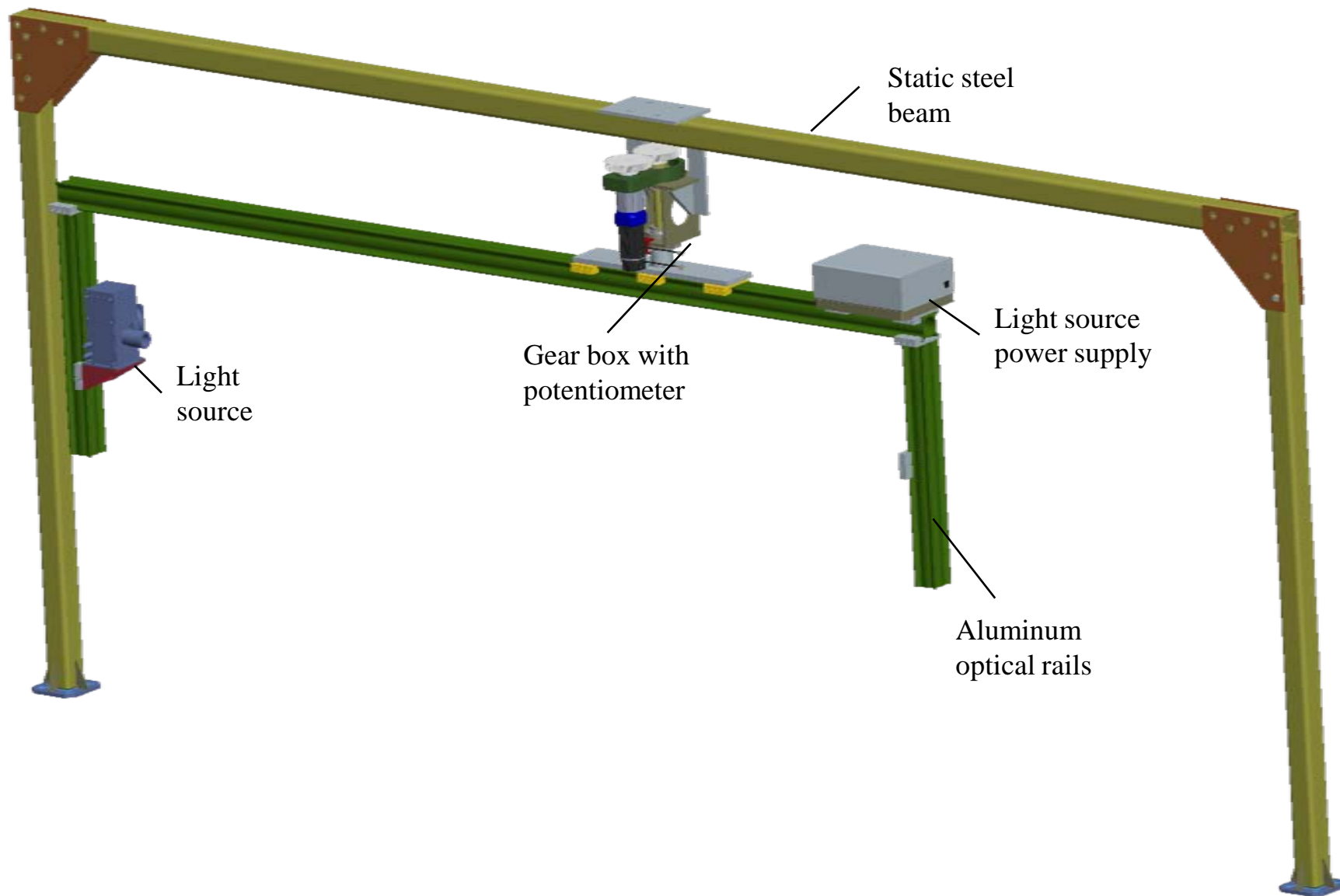


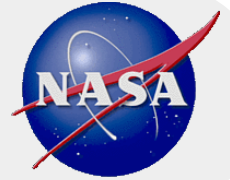
OMC Layout





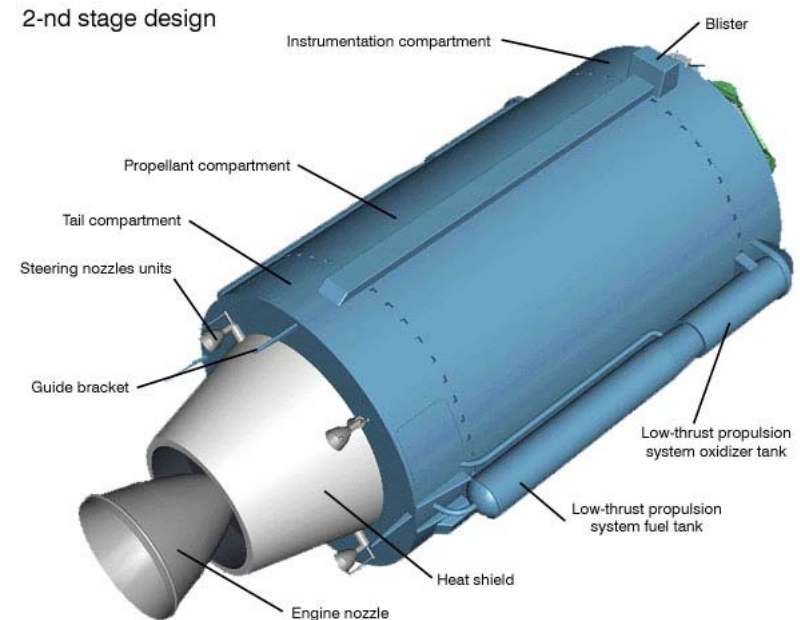
OMC Layout





Task I. Rocketbody lightcurves

- **Active Debris Removal task to help remediate the LEO environment.**
- **Start with observations of specific rocketbodies to acquire tumble rates**
- **Using scaled models of the specific rocketbody, photometric lightcurves can be acquired in laboratory for comparison to telescopic data**
- **First scaled model is SL-8 second stage with a simple, gray color scheme**
 - Scaled rocketbody will be studied using different rotation axes and other possible observation sampling methods
- **Second scaled model will also be SL-8 but painted with commercial (orange/white) color scheme**

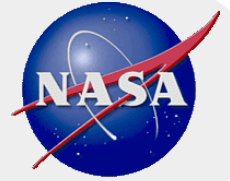


<http://danielmarin.blogspot.com/2010/04/lanzamiento-kosmos-3m-parus-99.html>



Task I. Rocketbody lightcurves



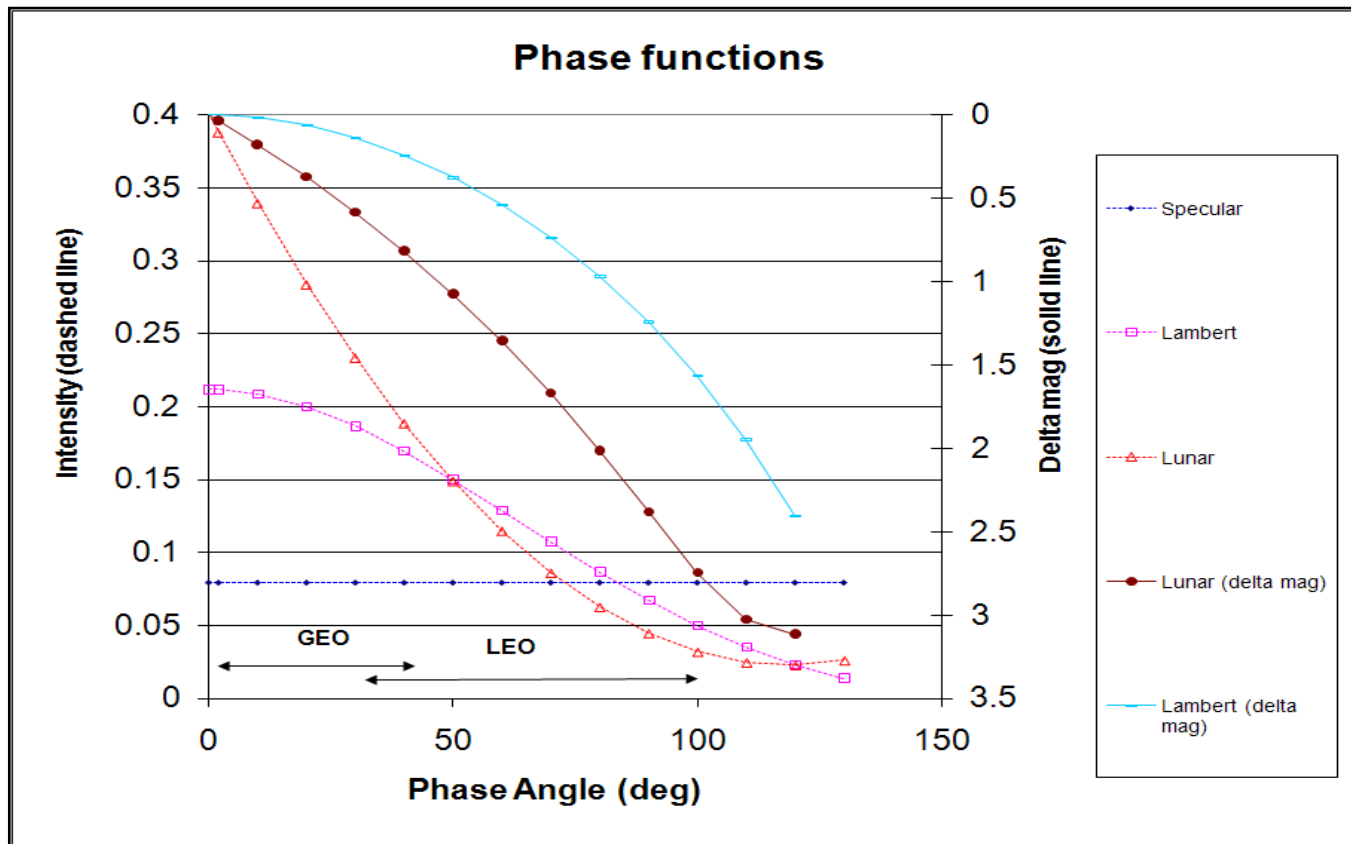


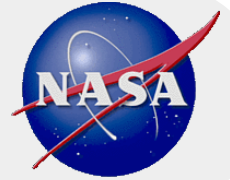
Task II. Phase functions

- For orbital debris size estimations using optical measurements, a Lambertian phase function is currently assumed:

$$\Psi(\alpha) = \frac{2}{3 \cdot \pi^2} [\sin(\alpha) + (\pi - \alpha) \cdot \cos(\alpha)]$$

$$d = \frac{2 \cdot R}{[\pi \Psi(\alpha)]^{0.5}} \cdot 10^{\left[\frac{M_{\text{obs}}(R) + M_{\text{sun}}(R)}{-5.0} \right]}$$





Task II. Phase functions

- **In 1993, Dr. M. Mulrooney proposed hybrid phase functions as a better fit to observed orbital debris (specular-Lambert combination and Lambert-Lunar).**
- **Using the OMC with calibrated targets, this phase function identification will be addressed.**
 - Calibrated targets include spheres and cylinders of different standard materials: pure aluminum and coated Duraflect ®
- **Once a “standard” phase function is established for well known Lambertian surfaces and aluminum surfaces, other materials will be investigated in order to provide a best fit for fragmentation debris.**



Task III. Fragmentation debris characterization (photometric and spectral data)

1. Characterizing the Orbital Debris Environment

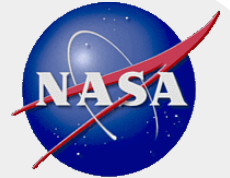
- Optical Measurements of debris-like fragments
 - Shape investigations
 - Filter photometry of known materials
 - Laboratory spectroscopy of returned surfaces, fragmentation debris from hyper-velocity ground tests, and original equipment manufacture spacecraft materials.

2. Optical characteristics of specific materials

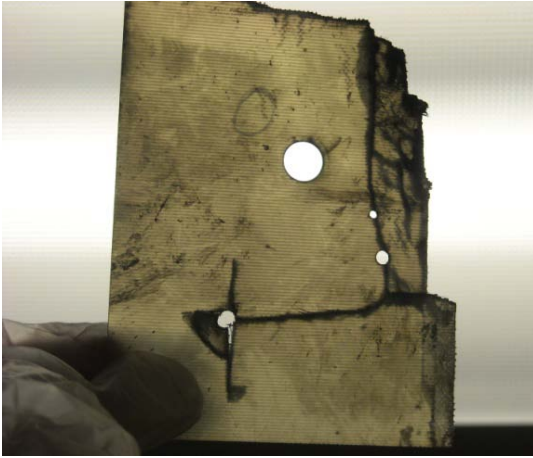
- Carbon Fiber Reinforced Plastic (CFRP) is nearly invisible in optical wavelengths
- Ground-test impacts with MLI appear to leave a thin film/coating due to the explosion (possibly adhered material dust particles or soot from the explosion) which significantly decreases its albedo and thus it's probability of detection in a laboratory, theoretically making it undetectable from ground telescopes

3. Application for telescopic data

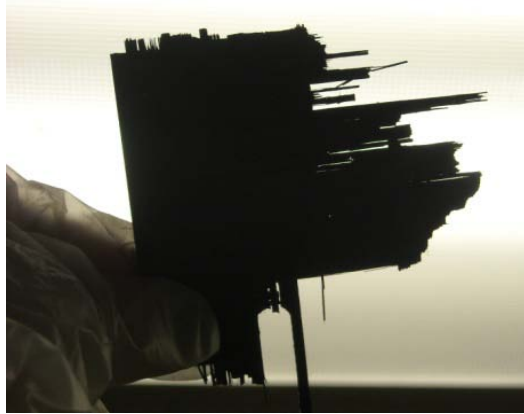
- In order for the laboratory data to be applicable to all optical users, the laboratory-based A/m values, color-index, and lightcurves must be provided for each target



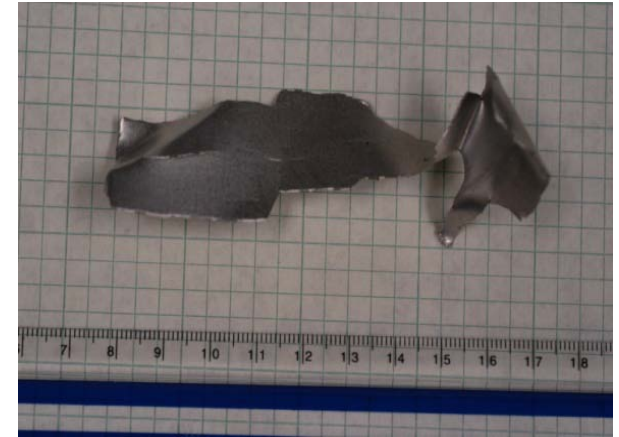
Task III. Fragmentation debris characterization (photometric and spectral data)



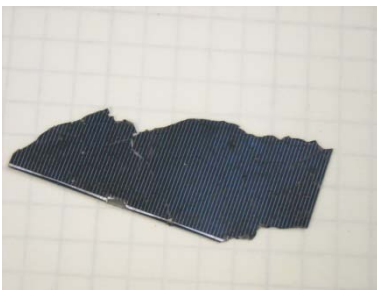
GFRP



CFRP



Aluminum Alloy



Solar cell



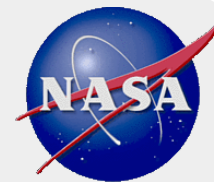
Electrical
potting



Aluminum
composite



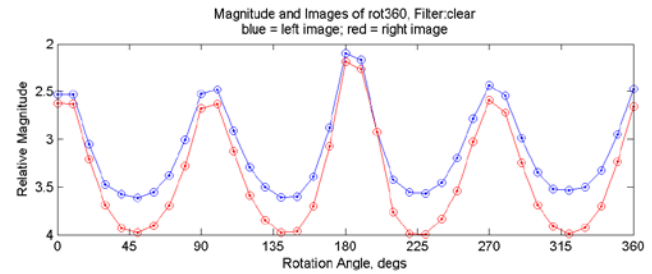
Electronics
composite



Task III. Fragmentation debris characterization (photometric and spectral data)

ID	Material	Source	Size: L_c (mm)	Mass (kg)	$\sim A/m$ (m^2/kg)
1	Intact MLI	Colleague	57.2	1.2×10^{-3}	2.1
2	Layer MLI: Space-facing Kapton	Colleague	58.2	3.9×10^{-4}	5.4
3	Layer MLI: Spacecraft-facing Kapton	Colleague	57.6	5.1×10^{-4}	4.2
4	Impacted MLI	Kyushu University	83.8	1.2×10^{-3}	5
5	Solar panel	Jet Propulsion Laboratory	~ 60	5.2×10^{-3}	0.5
6	Intact Solar cell	Spectrolab	50.1	4.4×10^{-3}	0.4
7	Fragment Solar cell	Kyushu University	23.8	3.1×10^{-4}	1
8	Aluminum	ESOC2	56.5	2.6×10^{-3}	1
9	Glass Fiber Reinforced Plastic	Kyushu University	95.9	1.7×10^{-2}	0.4
10	Carbon Fiber Reinforced Plastic	Kyushu University	66.3	3.2×10^{-3}	1
11	Nugget – Electronic Potting Material	SOCIT4	17.7	1.3×10^{-3}	0.3
12	Electronic Circuit Board	SOCIT4	49.2	7.1×10^{-3}	0.2
13	Flake- Aluminum	SOCIT4	22.5	1.0×10^{-3}	0.5
14	Potted Electronics	SOCIT4	64.0	2.2×10^{-2}	0.2

Task III. Fragmentation debris characterization (photometric and spectral data)



Total Image 0.4 sec exposure

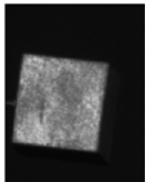
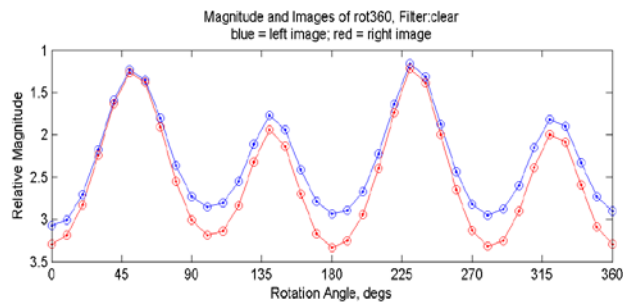
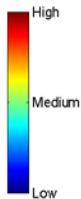
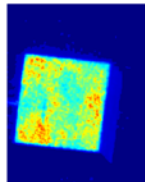


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0.4 sec exposure



Total Image 0.4 sec exposure

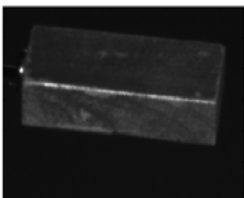
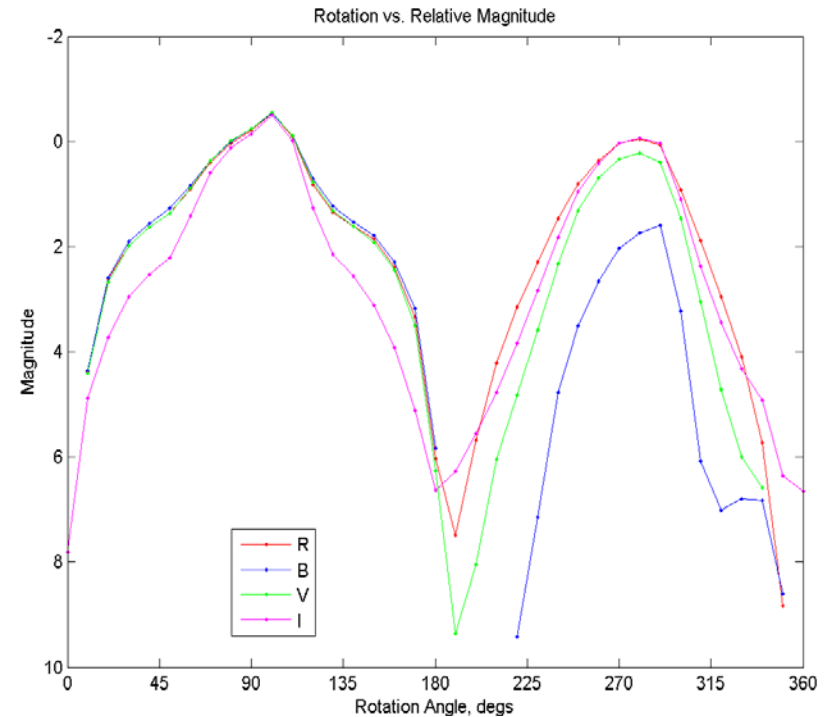
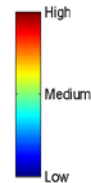
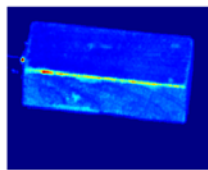
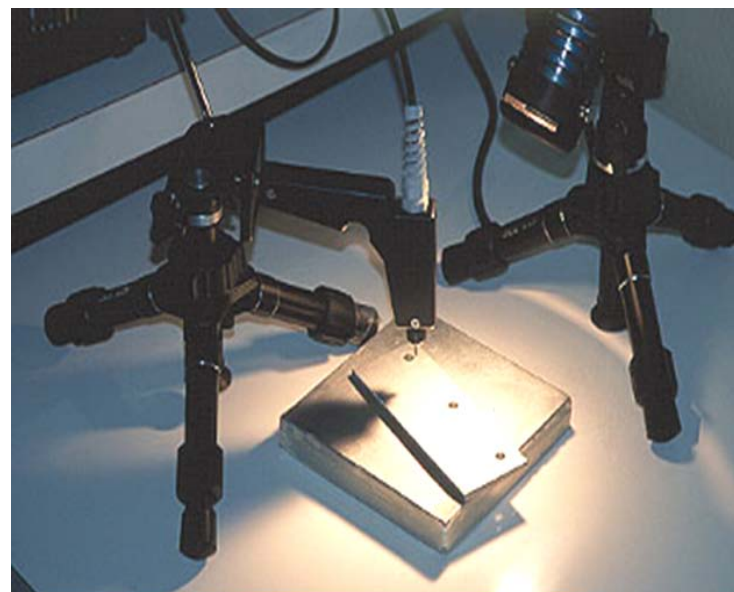
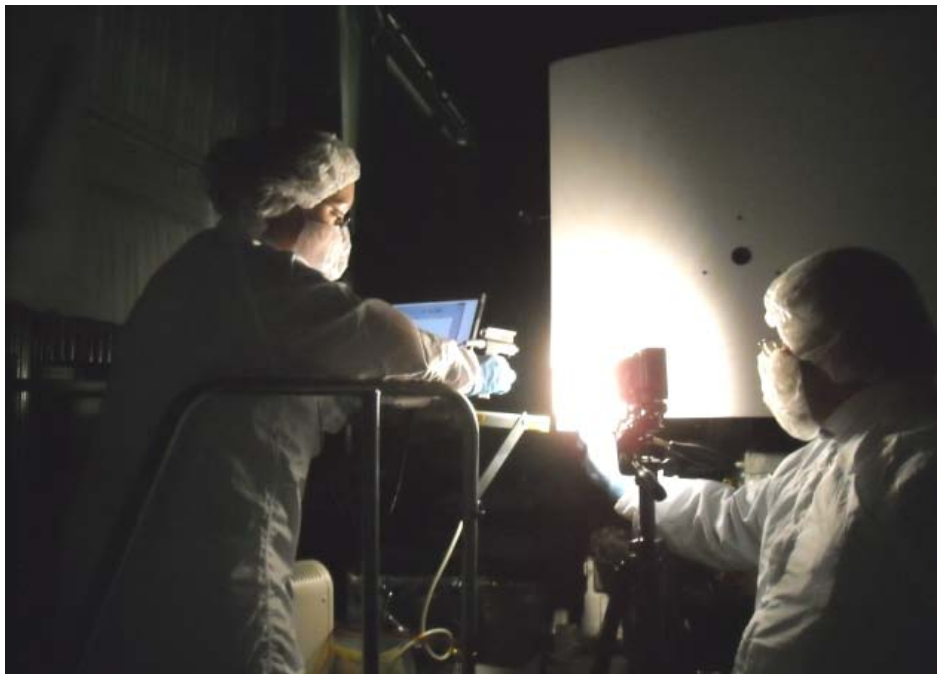


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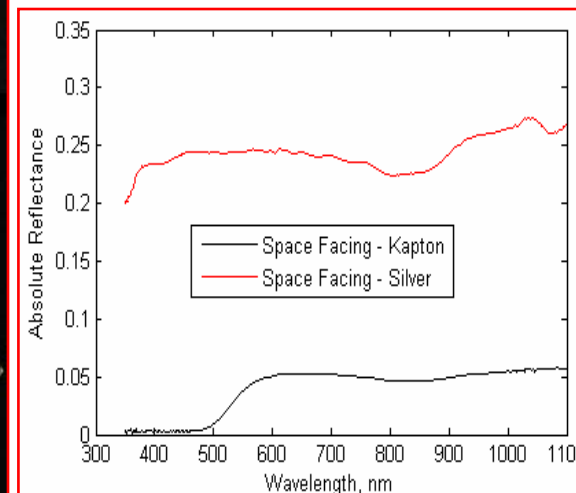
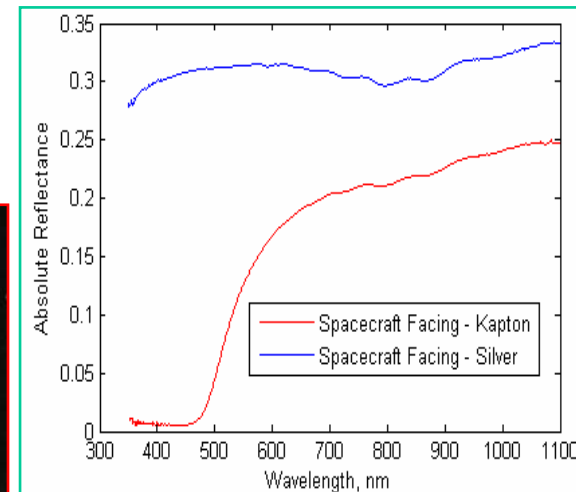
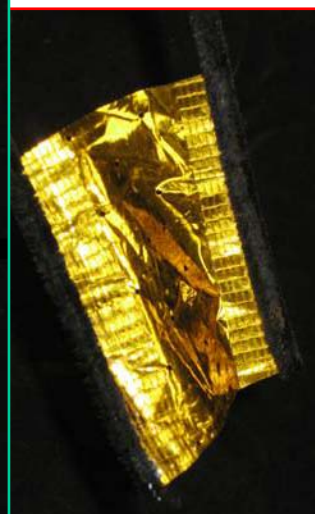
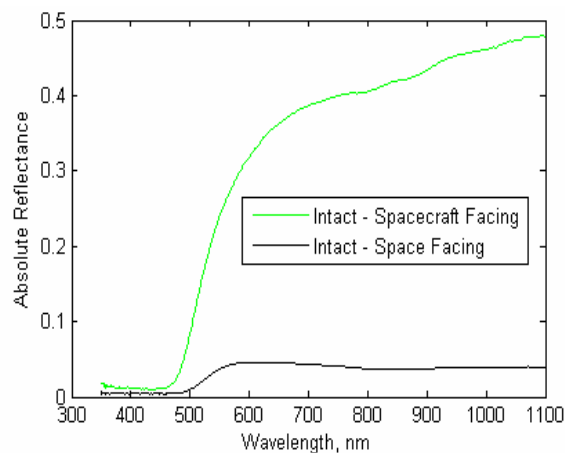


Task III. Fragmentation debris characterization (photometric and spectral data)





Task III. Fragmentation debris characterization (photometric and spectral data)





Task IV. Development of Optical Size Estimation Model (OSEM)

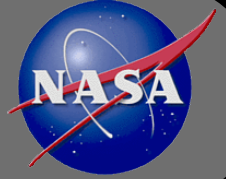
- An object's resultant brightness is dependant on three principal factors: albedo, phase function and illumination aspect angle.
- Overall goal is to define albedo distribution, as it is the dominant factor in brightness determination.
- Laboratory goals:
 - To define color response of specific materials as a function of rotation of aspect angle and phase angle.
 - A low-fidelity BRDF will also be determined in the laboratory
 - A Spectralon® panel will be used as the white reference
 - A optical mirror will be used to determine the albedo of different materials
- Using the photometric lightcurve acquisition, spectral data, and phase function investigation, the data will be used to build upon the development of the OSEM.
- OSEM development work will be led by Dr. Matt Hejduk (a.i. solutions); participants include:
 - Dr. Kira Abercromby (California Polytechnic State University)
 - Dr. Phillip-Anz-Meader (ESCG\JACOBS)
 - Dr. Heather Cowardin (ESCG\JACOBS)
 - Dr. Sue Lederer (NASA)
 - Dr. Mark Mulrooney (ESCG\MEI)

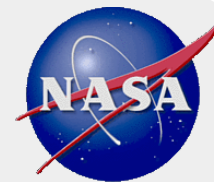
Task IV. Development of Optical Size Estimation Model (OSEM)



ID	Material	Material	B-V	B-R	B-I
1	Intact MLI	Space-facing, spacecraft-facing	+2.0±0.8	+2.9±1.1	+2.5±0.8
2	Layer MLI: Space-facing Kapton	Copper Kapton, Aluminized Kapton	+3.6±1.0, -0.1±0.1	+2.3±1.3, -0.1±0.2	+3.6±1.7, -0.3±0.6
3	Layer MLI: Spacecraft-facing Kapton	Aluminized Kapton, Copper Kapton	-0.1±0.1, +2.1±1.2	-0.1±0.1, +2.8±1.7	-0.8±0.5, +2.8±1.1
4	Impacted MLI	Layers of copper Kapton sandwiched with Mylar and beta cloth substitute	+0.1±0.2	+0.1±0.2	-0.9±1.0
5	Solar panel	Solar cell, aluminum honeycomb interior, CFRP backing	+1.9±0.1	+2.2±0.3	+0.6±1.0
6	Intact Solar cell	Aluminized backing, solar cell	+0.2±0.2	+0.1±0.5	-2.3±1.9
7	Fragment Solar cell	Aluminum back, solar cell	+0.2±0.2	-0.8±1.0	N/A
8	Aluminum	Aluminum alloy	+0.0±0.0	-0.1±0.1	-0.8±0.4
9	Glass Fiber Reinforced Plastic	Glass fiber reinforced plastic	+0.1±0.1	+ 0.1±0.2	N/A
10	Carbon Fiber Reinforced Plastic	Carbon fiber reinforced plastic	+0.1±0.1	+0.1±0.0	N/A
11	Nugget - Potting Material	Plastic potting material	+0.4±0.1	-1.3±0.8	N/A
12	Electronic Circuit Board	Plastic back side, electronics	+0.3±0.1	+0.1±0.3	-3.0±0.5
13	Flake- Aluminum	Possible aluminum with unknown surface contaminants	+0.0±0.0	+0.1±0.0	-0.6±0.4
14	Potted Electronics	Metals and plastics	+0.3±0.1	+0.5±0.1	+0.5±0.1

Back-Up Slides





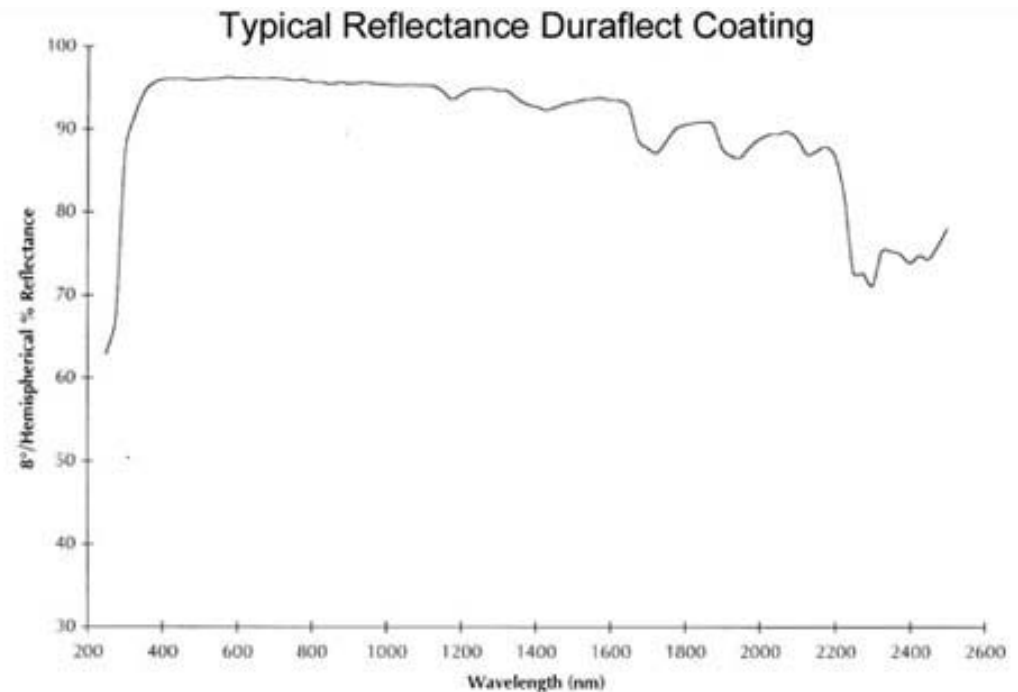
filters

Filter	Range (nm)	Central λ (nm)	FWHM (nm)
Johnson Blue	350-600	440	100
Johnson Visible	450-700	550	90
Bessell Red	560-1060	630	120
Bessell Infrared	700-1100	900	300



DURAFLECT®

- **Labsphere's Duraflect® White Reflectance Coating is a proprietary coating designed specifically for use in hostile weather conditions where a high Lambertian reflectance surface is required. Because this high reflectance coating is applied by spray onto a specially prepared surface, it has a greater degree of flexibility and faster application time than traditional tape coating. Spray coating allows for faster prototyping and ensures that final design is not limited by the application process.**





OMC objective

The OMC was designed in 2005 in order to obtain the following optical characteristics of orbital debris:

- **Generate lightcurves:**
 - Shape analysis
 - Comparison to telescopic data
 - Model real-scaled rocket-bodies to determine tumble axis (Liou)
- **Acquire filter photometry:**
 - Insight to material characteristics relative to telescopic data
 - Provide comparisons between laboratory and telescopic data via color index data
- **Investigate phase functions**
 - Current assumption follows Lambertian sphere assumption
 - Lab allows for comparisons to how debris-like fragments follow this phase function (follow-up to Mulrooney's thesis that suggested Hybrids may be a better fit)
- **Acquire laboratory spectroscopy:**
 - Provides truth data for materials
 - Expanding NASA spectral database to include more modern materials which previously were not available (Abercromby)
- **Provide insight to material risk & analysis**
 - Able to provide optical characteristics of specific materials relative to risk of impact
 - I.e, carbon fiber reinforced plastic is nearly invisible in optical wavelengths, possible to paint white for use in future spacecraft
 - I.e, ground-test impacts with MLI appear to have a film/coating due to explosion which minimizes reflectance and thus it's probability of detection remotely if the same film is also adhered to in space-explosions/collisions
 - I.e, Known A/m values, color-index, lightcurves to compare with remote data of unknown targets, application for all optical users is characterizing orbital debris environment
- **Develop an albedo distribution/Optical Size Estimation Model**
 - Work towards defining an albedo distribution for the current fragments to relate to actual space debris
 - This distribution will be built into modeling the first optical Size Estimation Model